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THE GENESIS OF LAKE AGASSIZ:[1] A CONFIRMATION

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INTRODUCTION

In a paper published in the *Journal of Geology* in 1896, J. B. Tyrrell stated that the results of his field work in the region lying to the west and southwest of Hudson Bay showed that—

> the Keewatin glacier seems to have retired northward well into Manitoba and possibly even beyond the northern limit of that province before it was joined by the eastern glacier. When they united the water was ponded between the

[1] Published by permission of the Director of the Geological Survey of Canada.

fronts of the two glaciers to the north and northeast and the high ground to the south and west. Thus Lake Agassiz had its beginning. Its waters rapidly rose until they overflowed southward into the valley of the Mississippi and then gradually declined as River Warren deepened its channel.[1]

By his more recent work in the region lying to the south of Hudson Bay, Tyrrell has shown that the last invasion of glacial ice in that region was by an ice sheet which advanced in a southwesterly direction and overlapped a portion of the area previously occupied by an ice sheet which he named the Patrician Glacier. This last advance of the ice extended in a southwesterly direction at least as far as the headwaters of the Severn River and in a westerly direction approximately as far as the Hayes River, where it was met by a readvance of the Keewatin glacier.[2]

Field work done by the writer during portions of the seasons of 1913 and 1914 in the vicinity of the Rainy River and Lake of the Woods, Ontario, has brought forth evidence which confirms Tyrrell's view that Lake Agassiz had at first a rising stage, due to the blocking of the northward drainage, and later subsided, and that, during the entire existence of the lake, the ice border was far to the north and northeast. This conception of the life-history of Lake Agassiz differs radically from that of Warren Upham, by whose work Lake Agassiz is best known, and whose interpretation has been most widely accepted. The object of the present paper is to present the evidence which confirms Tyrrell's view as to the genesis of Lake Agassiz and to point out that the acceptance of this view has an important bearing upon the question of the character and cause of the epeirogenic movements which deformed the shore lines of Lake Agassiz.

UPHAM'S CONCEPTION OF THE LIFE-HISTORY OF LAKE AGASSIZ

Glacial Lake Agassiz is best known from the work of Warren Upham, the results of which were published in 1895 by the United States Geological Survey as *Monograph 25*. Upham's field work in connection with the investigation of the basin of Lake Agassiz was done some thirty years ago and was largely confined to the

[1] J. B. Tyrrell, "The Genesis of Lake Agassiz," *Jour. Geol.*, IV (1896), 813.

[2] J. B. Tyrrell, "The Patrician Glacier South of Hudson Bay," *Congrès Géologique International, Canada, 1913, Compte-Rendu* (Ottawa, Canada, 1914), pp. 523–34.

western or prairie portion of the basin. At that time little was known of the extension of the lake in the northern portion of the state of Minnesota or in the adjoining portions of Canada, for much of this region was densely wooded, largely unsettled, and difficult of access. At that time, also, the general conception was that during Pleistocene time the Laurentide glacier occupied the greater portion of Central and Northwestern Canada. It was not until some time later that the subdivision into Keewatin and Labradorean ice fields was recognized.

Upham believed, as the result of his investigations, that the northward drainage of Red River valley and adjacent areas was ponded between the retreating front of the Laurentide glacier on the north and northeast and the divide on the south, that the lake had at first a small beginning in the southern part of the basin and gradually grew in size as the ice withdrew toward the northeast, and that a great series of moraines was deposited in the waters of the lake at stages of halt or slight readvance during the general retreat of the ice sheet. He found that the lake, during its higher stages, discharged southward to the Mississippi along the course of the present Lake Traverse and Minnesota River valleys. During the operation of the southern outlet several strong shore lines of the lake were developed. As the ice retired and uplift took place, lower outlets were opened toward the northeast and other and lower beaches were developed in the northern part of the basin. He also showed that beaches which are single in the southern portion of the basin split into series in the northern portion of the basin and rise differentially toward the north-northeast, the highest being most upwarped and the lowest least, thus proving that differential elevation of the land went on during the existence of the lake.[1]

DIFFICULTIES IN ACCEPTING UPHAM'S INTERPRETATION

Some of the difficulties involved in accepting Upham's interpretation of the life-history of Lake Agassiz were pointed out by T. C. Chamberlin. It was found by Upham that the uppermost or Herman beach was continuous for a long distance northward

[1] Warren Upham, "The Glacial Lake Agassiz," *U.S. Geol. Survey, Monograph 25*, 1895.

and that it overrode three prominent moraines which marked halts or readvances of the ice front. Upham supposed that the Herman beach represented the whole time of the formation of the several moraines and of the retreat of the ice front for at least 250 miles, in spite of the fact that he found the beach to be not very massive and not very notably stronger in the southern than in the northern portion. Recognizing this difficulty, Chamberlin suggested that "the whole history of Lake Agassiz may not have fallen within the period of stationary or rising crustal movement but that the early part of it may have taken place during the latter portion of the period within which the crust was being depressed."[1] In this way it may be supposed that shore lines were formed at early stages of the lake but were later submerged. The uppermost Herman beach would have been formed at the time of maximum submergence. It would be all of one age and would represent a comparatively short time.

Another difficulty arises from the character of the deposits laid down in the basin of the lake. Upham held that the greater part of these deposits were derived from the ice sheet and its inclosed drift—a necessary inference from his interpretation of the history of the lake. But he found that "bowlders are absent or exceedingly rare in the beaches, deltas, and finer lacustrine sediments."[2] If it is true that a series of moraines was deposited in the lake, and if the sediments of the lake basin were largely derived from the ice sheet, it seems highly probable that berg deposits would form an important part and that bowlders would be included in the sediments.

A serious difficulty also arises if Upham's interpretation of the mode of origin of the sediments which occur in Red River valley is accepted. Upham held that these sediments are recent fluvial deposits laid down in local depressions and on flood plains of streams after the disappearance of Lake Agassiz. The deposits, he states, "have commonly greater thickness and extent than the underlying silt of glacial Lake Agassiz."[3] In the southern portion of the basin they are in places underlain at considerable depths by "sheets of turf,"[4] etc., apparently indicating the presence of an old soil. The

[1] "The Glacial Lake Agassiz," *U.S. Geol. Survey, Monograph 25*, p. 245.

[2] *Ibid.*, pp. 183 and 201. [3] *Ibid.*, p. 202. [4] *Ibid.*, p. 253.

great thickness and extent of these deposits and the occurrence of "sheets of turf" in their lower portions seem difficult of explanation on the assumption that they are "recent fluvial deposits."

All these difficulties disappear, however, if it is considered, as the evidence seems to show, that Lake Agassiz had at first small beginnings in Red River valley and gradually rose until it overflowed to the south, owing to a blocking of the northward drainage by an advance of the ice, and that the ice advanced only into the northern portion of the basin, so that the whole southern part of the lake was practically free from ice during the entire existence of the lake.

RECORDS OF LAKE AGASSIZ IN RAINY RIVER–LAKE OF THE WOODS DISTRICT

Geographical relations of the district.—The eastern portion of Rainy River–Lake of the Woods district lies about midway between Lake Superior and the Red River of the province of Manitoba. The Rainy River connects Rainy Lake and Lake of the Woods and for a distance of 82 miles forms the international boundary between the state of Minnesota and the adjoining portion of the province of Ontario. The Rainy River, the main stream of the region, flows westward to Lake of the Woods, which drains northwestward to Lake Winnipeg and thence to Hudson Bay, so that the whole area lies within the Hudson Bay drainage system. The altitude of Rainy Lake is 1,107 feet and of Lake of the Woods 1,060 feet above the sea, and the general altitude of the plain bordering the Red River on the west is about 200 feet lower. The southern portion of Lake of the Woods is shallow and is generally bordered by drift deposits. The divide southwest of the lake, separating the lake basin from that of the Red River on the west, is low and for some distance is less than 30 feet above Lake of the Woods. On the northwest, near Northwest Angle, the divide is also only a few feet above the level of the lake, so that the plains of Manitoba and northern Minnesota are practically continuous on the southwest and northeast into the southern portion of the Lake of the Woods basin. In southeastern Manitoba, and west of the southern portion of Lake of the Woods, the continuity of the plain's surface is broken

by a relatively high area which rises to a maximum height of about 200 feet above the general level of the plains. The area lying between Rainy Lake and Lake of the Woods is so deeply drift-covered that comparatively few solid-rock exposures occur. The surface has generally very slight relief, and slopes gently toward the west, so that the area really forms a portion of the eastward extension of the wooded portion of the prairie plains of Manitoba and northern Minnesota, from which it is separated by the shallow basin of the southern portion of Lake of the Woods. In the northern portion of Lake of the Woods and north of a line drawn from the central part of the lake southeastward to Rainy Lake, the country is generally rocky and has comparatively little drift covering.

Till sheets.—There are at least two distinct till sheets in the district. The upper and younger is distinguished from the lower and older till sheet by the calcareous nature of its materials, and by the presence in it of bowlders of limestone and other rocks which are known to outcrop in Manitoba, but not in the district itself nor in the region lying to the northeast. Striae observed on the bedrock beneath the till sheet trend southeastward or eastward. These striae were not seen to be crossed by later striae, and no till was seen to overlie this till sheet. It seems evident, therefore, that the calcareous till was deposited by a lobe of the Keewatin glacier and that the area in which the calcareous till occurs was not overridden by an advance of ice from the northeast at a later time.

The lower and older till sheet was deposited by an ice sheet advancing from the northeast. This is shown by the southwestward trend of striae on the bedrock underlying this till sheet and by the fact that the till contains no limestone similar to that which occurs in the upper sheet. Associated with the lower till sheet are considerable deposits of fluvio-glacial sands and gravels which also contain no limestone. No evidence was seen which would suggest that there was any considerable lapse of time between the deposition of the two till sheets, and it is presumed that they were nearly contemporaneous in age and were deposited during the Wisconsin stage of glaciation.

Laminated stony clays.—A series of laminated clays, containing in places striated stones and bowlders, occurs in the district. The

clays overlie and in the eastern portion of the district also underlie the calcareous till, with which they are closely associated. In some sections there is a sort of transition upward from the unstratified till into the laminated clays; that is, in the lower portion of the clays distinct laminae of clay are separated by unstratified stony material resembling the underlying till. The stony layers at the base rarely exceed a few inches or at most a foot in thickness and rapidly die out, so that "the transition beds" are, as a rule, only 4 or 5 feet thick. The laminated clays in the district range in altitude from 1,060 up to at least 1,200 feet, but they are generally only a few feet in thickness. These clays were deposited in a glacial marginal lake which is here referred to as Early Lake Agassiz. This lake was associated with an advance of the Keewatin glacier which deposited the calcareous till in the region. The clays were in part deposited during the time of advance of the ice sheet, for in places till overlies the clays. This relation is well seen in the sections exposed in the gravel pit one and one-half miles west of Fort Frances, where 8 feet of calcareous till overlie laminated clays, which are again underlain by non-calcareous, fluvio-glacial sands and gravels. The laminated clays were also in part deposited during the time of retreat of the ice. Early Lake Agassiz was, however, largely if not wholly drained before the later Lake Agassiz came into existence, for the desposits of Lake Agassiz rest unconformably on the calcareous till and on the closely related laminated clays.

Deposits of Lake Agassiz.—Numerous raised beaches of Lake Agassiz occur in the district, at altitudes ranging from 1,100 to 1,200 feet. The strongest and best-developed beach extends northward for some distance from the vicinity of the town of Rainy River. The altitude of this beach near the town of Rainy River is 1,117 feet. Ten miles northeast of this locality its altitude is about 1,125, and twenty-four miles northeast its altitude is about 1,140. Higher beaches occur at various altitudes up to at least 1,200 feet. A comparatively small part of the drift-covered area lying between Rainy Lake and Lake of the Woods rises more than 1,200 feet, but in the northern portion of Minnesota immediately south of Rainy River district drift-covered areas rise considerably higher. In this

area a number of beaches rising well above 1,200 feet have been found by Mr. Leverett, who states that bars of gravel and sand formed by the waters of Lake Agassiz occur on the highest points of Beltrami Island.[1]

The lacustrine deposits of Lake Agassiz in the district occupy areas of considerable extent and are in places at least 30 feet thick. They are generally even-bedded but not strongly laminated. In places they are characterized by an irregular alternation of sandy and clayey layers and occasionally thin gravelly layers. The beds are in places more sandy toward their base than in their upper portion, and are frequently ripple-marked but not cross-bedded. The material is more oxidized than that of the older laminated stony clays, and there can be little doubt that the material was derived from erosion of land surfaces by wave and stream action. The sandy ripple-marked beds underlying clay, and the occurrence of gravelly layers interbedded with sandy and clayey layers are explained by the fact that the sediments were deposited in a rising body of water. The lacustrine beds are also characterized by the presence, in their lower portions at least, of fossil fresh-water shells. Fossil fresh-water shells also occur in some of the beach ridges at various altitudes up to 1,149 feet, or 88 feet above Lake of the Woods.

Unconformity at the base of Lake Agassiz sediments.—The evidence found in Rainy River district, which confirms Tyrrell's contention that Lake Agassiz had at first a rising stage, is based largely on the fact that the sediments deposited in Lake Agassiz rest unconformably upon the underlying deposits; that is, a period of erosion intervened after the deposition of the calcareous till and associated laminated stony clay, and before the later lacustrine sediments were laid down.

This is well shown in numerous sections exposed along the Rainy River and around the shores of the southern portion of Lake of the Woods. Fig. 1 illustrates the character of one of these sections which has been exposed by wave erosion on the present shore of Lake of the Woods at its southern side. At the base a

[1] Frank Leverett, "Surface Formations and Agricultural Conditions of Northwest Minnesota," *Minn. Geol. Soc., Bull. No. 12*, 1915, p. 37.

small thickness of calcareous till is exposed, passing up into laminated, stony clay which is overlain unconformably by Lake Agassiz lacustrine clays containing fresh-water shells. The contact is a wave-cut plain. The lacustrine deposits above the wave-cut plain are clayey in character and evenly and thinly bedded, so that it is evident that the water must have risen to a considerable height to permit of such deposition. In places around the southeastern portion of Lake of the Woods these lacustrine deposits are at least

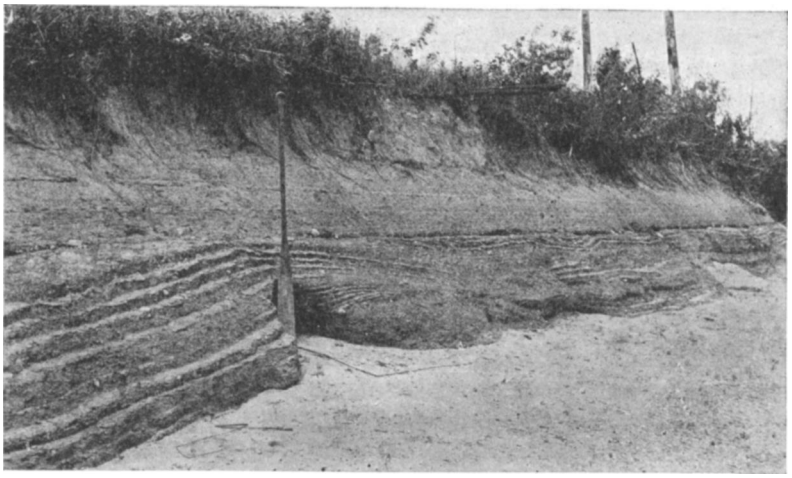

FIG. 1.—Section exposed on south shore of Lake of the Woods, showing at the bottom calcareous till passing upward into laminated, stony clays unconformably overlain by Lake Agassiz lacustrine clays. The contact is a wave-cut plain.

30 feet thick and rise to an altitude higher than the divide separating the Lake of the Woods basin from that of the Red River on the west. Furthermore, the first strong raised beach above the level of Lake of the Woods, at the level of which the water must have stood, if not at some higher level, when the lacustrine deposits were laid down, is in the southern portion of the district from 45 to 55 feet above the level of Lake of the Woods; and this beach passes over the divide to the southwest of the lake.[1] Hence it follows that these lacustrine deposits were not laid down in a local lake

[1] *Minn. Geol. Survey, Bull. No. 12,* 1915 (map).

but in a body of water which covered not only the Rainy River and Lake of the Woods districts but also occupied Red River valley, and that this was the last great glacial-marginal lake in the region, viz., Lake Agassiz.

Numerous sections also show that weathering and erosion took place during the interval of erosion before the deposition of Lake Agassiz sediments. This is well shown in sections along the Rainy River from one to three miles below the town of Rainy River. In places, small stream valleys were eroded and later partially or wholly filled with lacustrine deposits. This relation is well seen in the small creek valley which enters the Rainy River three miles below Fort Frances. In one place, on Buffalo Point on the southwest side of Lake of the Woods, thin peaty bands occur in the lower portion of Lake Agassiz deposits.

The sections exposed on the south shore of Lake of the Woods (Fig. 1) afford a demonstration that the water must have risen to a sufficient height to permit of the deposition of the fine lacustrine clays overlying the old wave-cut beach, and it is clear that these waters formed part of Lake Agassiz during a rising stage. There is evidence in the district that the waters rose through a vertical interval of at least 60 feet; for the lake clays are unconformable on the underlying sediments throughout this vertical interval. The highest shore line found in Rainy River district has an altitude of 1,200 feet. During the highest stages of the lake, practically the entire district was submerged and the highest shore line, if there had been land high enough to have received it, would have a present altitude of approximately 1,350 feet, as estimated from Upham's determination of the highest beaches in other parts of the basin. It is not certain that the water rose to the level of the highest shore lines recognized in other portions of the basin; but it seems probable that it rose to the uppermost strong beach (Herman), because this beach, as already stated, is continuous for a long distance northward and is apparently all of one age. It is possible that the Milnor beach which Upham found to be traceable for only a short distance in the southern part of the basin marks a shore line of Early Lake Agassiz, but the extent of this lake or of any of its shore lines is not definitely known. This lake was largely drained

before Lake Agassiz came into existence and its sediments are buried beneath those of Lake Agassiz.

It is at least certain that the waters of Lake Agassiz stood at one time at about the present level of Lake of the Woods, and that they later rose considerably higher. It seems probable also that the lake which preceded Lake Agassiz was almost completely drained, and that Red River valley was a land surface before the latest advance of the ice brought Lake Agassiz into existence; for the character of the deposits in Red River valley, which Upham[1] regarded as post-Lake Agassiz fluvial deposits, suggests rather that they are lacustrine deposits and that they are unconformable on the underlying sediments.

Regarding these deposits Upham stated:

> Thus the occurrence of shells, rushes and sedges in these alluvial beds at McCauleyville, Minnesota, 32 and 45 feet below the surface or about 7 and 20 feet below the level of Red River, of sheets of turf, many fragments of decaying wood and a log a foot in diameter at Glyndon, Minnesota, 13 to 35 feet below the surface, and numerous other observations of vegetation elsewhere along the Red River valley in these beds, demonstrate that Lake Agassiz had been drained away, and that the valley was a land surface subject to overflow by the river at its stages of flood when these remains were deposited.[2]

He also stated: "The deposits have commonly greater thickness and extent than the underlying silt of glacial Lake Agassiz."

It is evident that a land surface existed in Red River valley before these sediments were laid down; but it seems probable that the sediments are largely lacustrine in origin and not fluvial. G. M. Dawson, in describing the section across Red River valley near the international boundary stated that the valley is floored with a fine silty deposit, a portion of the upper layers of which may have been formed by the overflow of the river itself. He described the typical deposit as of great thickness and consisting of fine yellowish, marly, and arenaceous clay, holding considerable calcareous matter, and effervescing freely with an acid.[3] The great extent and thickness and the high calcareous content of the clays

[1] Warren Upham, *U.S. Geol. Survey, Monograph 25* (1895), p. 253.

[2] *Ibid.*, p. 202.

[3] G. M. Dawson, *Report on the Geology and Resources of the Region in the Vicinity of the Forty-ninth Parallel*, 1875, pp. 248–49.

would seem to show that they are lacustrine in origin and not fluvial. It seems probable that they are Lake Agassiz deposits and that they are unconformable upon the underlying sediments.

It is concluded, therefore, with Tyrrell, that after the retreat of the Keewatin glacier well toward the north there was comparatively free drainage to the north and that a later advance of the ice from the northeast was met by a slight readvance of the Keewatin glacier, which resulted in the ponding of the northward drainage and the inception of Lake Agassiz. It is not certain just how far the latest advance of the ice extended. It did not reach Rainy River district, for the calcareous till derived from Manitoba is not overlain by till derived from the northeast, and the southeastward- and eastward-bearing striae are not crossed by later striae. At Stony Mountain, near Winnipeg, southeastward-bearing striae cross striae trending nearly south, but are not themselves crossed by later striae. Tyrrell found that along the east side of Lake Winnipeg southwestward-bearing striae cross earlier striae bearing nearly southward.[1] Tyrrell[2] also held that the "Winnipeg Moraine" represented by islands in Lake Winnipeg and developed in places along the western shore of the lake marked the termination of the Labradorean glacier. It seems evident that during the life of the last great glacial marginal lake of the region, viz., Lake Agassiz, the ice margin in Manitoba was at no time farther south than the southern portion of Lake Winnipeg, and that the whole southern portion of the lake was practically free from ice. Lake Agassiz was associated with a readvance of the ice sheet, chiefly of the Labradorean glacier at a very late time during the Wisconsin stage of glaciation, and its disappearance followed the final withdrawal of ice sheets from the region.

BEARING OF THE LIFE-HISTORY OF LAKE AGASSIZ ON THE QUESTION OF THE CHARACTER AND CAUSE OF THE DIFFERENTIAL UPLIFT

If it is true, as seems probable, that during the existence of Lake Agassiz the ice border was far north of the southern end of the lake, this fact has an important bearing on the character and

[1] J. B. Tyrrell, *Amer. Geol.*, VIII, 21.

[2] *Bull. Geol. Soc. Amer.*, XXIII (1911), 733.

cause of the differential uplift which is shown to have taken place by the deformation of the shore lines of the lake.

It is known that the whole of the southern portion of the Lake Agassiz basin was affected by uplift but that the region south of the southern outlet of the lake was unaffected, for the abandoned shore line of Lake Dakota in this region is apparently nearly horizontal.[1] That is, there is a sort of "hinge-line" here. The location of this "hinge-line" was not due to "quick recovery of the crust by uplift" following removal of the ice from the immediate neighborhood, for the ice border was at least 250 miles north of the location of the "hinge-line."

The question also arises whether, as Chamberlin suggested, the land was being depressed during the time of advance of the latest ice sheet. It would be possible to determine this if the present altitude with respect to sea-level of the beaches which were made during the rising stage of the lake could be determined. It was found in Rainy River district that the strongest beach of Lake Agassiz apparently marks a long stand of the waters during the rising stage and again during the subsiding stage; for the beach deposits show evidence of having been partly eroded and spread out by the rising waters and beach ridges having a slightly different trend were later built on the older deposits. This would seem to show that the land was already depressed during the rising stage of the lake, but the evidence is not very conclusive. In the case of the "fossil" shore line seen in sections along the south shore of Lake of the Woods (see Fig. 1), it was found that the beach maintains the same altitude in a direction corresponding to the trend of the isobases of the beaches formed during the subsiding stage of Lake Agassiz. It is not known whether it rises toward the northeast, for unfortunately no record of its occurrence could be found in the northern part of Lake of the Woods.

The evidence suggests, but does not prove, that if, as seems probable, the uplift of the land was due to isostatic readjustment following the removal of the burden of the ice sheets, there was no close sympathetic relation; but that uplift lagged[2] considerably

[1] *U.S. Geol. Survey, Monograph 25*, p. 267.

[2] J. Le Conte, *Bull. Geol. Soc. Amer.*, II (1891), 329–30; W. B. Wright, *The Quaternary Ice Age*, 1914.

behind the removal of the great mass of the Wisconsin ice sheets and was only completed after the final retreat following the latest advance of the ice.

SUMMARY

Evidence bearing on the life-history of Lake Agassiz, found in the Rainy River–Lake of the Woods district, Ontario, confirms Tyrrell's conclusion that Lake Agassiz had at first a rising stage. The evidence is based largely on the fact that an unconformity exists at the base of the Lake Agassiz lacustrine sediments. The lake was associated with the latest advance of ice sheets, chiefly of the Labradorean glacier, during the Wisconsin stage of glaciation. An earlier glacial marginal lake, which is herein referred to as Early Lake Agassiz, was associated with a lobe of the Keewatin glacier; but this lake was largely if not wholly drained before Lake Agassiz came into existence. The latest advance of the ice into the Lake Agassiz basin did not extend farther south than the southern portion of Lake Winnipeg, so that the ice border of Lake Agassiz was at least 250 miles north of the southern end of the lake during the entire existence of the lake.

The acceptance of this interpretation of the genesis of Lake Agassiz has an important bearing on the question of the character and cause of the differential uplift which is shown to have affected the region by the deformation of the shore lines. The evidence suggests, but does not prove, that if the uplift was due to isostatic readjustment following the removal of the burden of the ice sheets, there was no close sympathetic relation, but that, as Le Conte and Wright have supposed, uplift lagged considerably behind and was only completed after the final retreat following the latest advance of the ice sheets of the Wisconsin stage of glaciation.